Impact of improved inter row management on productivity, soils and greenhouse gas emissions in apple and cherry orchards

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Applied Horticultural Research

Project Number: MT12047

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MT12047

R&D projects: co-investment funding

This project has been funded by Horticulture Innovation Australia Limited with co-investment from Applied Horticultural Research and funds from the Australian Government.

ISBN <HIA Ltd to add>

Published and distributed by:
Horticulture Innovation Australia Ltd
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1 Summary

The orchard floor management in perennial fruit crops has the potential to impact on the productivity, soils and greenhouse gas emissions from apple and cherry orchards.

In this study, on a commercial apple orchard at Orange, NSW and a cherry orchard at Young, NSW, the following orchard floor practices were examined; **control** reflected industry practice with herbicides used to prevent weed growth and tree organic matter (pruning, leaf and fruit fall) input left, **scrape** treatment herbicides were used to prevent weed growth and all organic matter input was removed, **wheat straw mulch**, **lucerne straw mulch** (apple orchard site only), or **compost** (cherry orchard only) applied evenly under the treeline. The mulch and compost was applied in November 2013 and June 2015. The inter-row was managed either as the Control with a mown grass sward maintained or Scrape with no grass cover and all organic matter input removed from the inter-row. Over the project the greenhouse gases impacts were assessed via measurement of soil nitrous oxide emissions along with changes in soil carbon. Productivity was assessed through fruit yields and quality.

Very low baseline nitrous oxide emissions were measured from the control in both apple and cherry orchards in NSW. Annual soil nitrous oxide emissions ranged between 0.3 to 0.7 kg N_2O-N ha^{-1} $year^{-1}$, which are among the lowest reported for Australian agriculture. These low annual emissions were due to low nitrogen fertiliser use, cool temperate growing conditions and micro-irrigation systems in the orchards.

The orchard floor practices which added low C:N amendments (lucerne straw mulch or compost), increased annual nitrous oxide emissions by 2.7 and 3.8 times over the control. Neither addition of wheat straw mulch or removal of all organic matter input in the scrape treatments affected annual nitrous oxide emissions.

An increase in soil carbon storage was only observed under the compost treatment at the cherry orchard, with soil microbial biomass also increasing. In the apple orchard no change in soil carbon storage or soil microbial biomass was observed following the application of the treatments.

Cherry or apple yields were not affected by the treatments except when lucerne straw mulch was applied to the apple orchard. The impact on fruit quality in both the apple and cherry orchard and the different cultivars was generally small and variable between years. In the short term adding (Mulches and Compost) or removing (Scrape) organic matter inputs did not produce clear changes in a range of fruit quality parameters.

The nitrous oxide derived emissions intensity, that is the emissions per tonne of fruit, for these apple and cherry orchards were among some of the lowest reported in the world. This was due to the good yields and low nitrous oxide emissions from the orchards. This information adds to the environmental credentials of Australian grown apples and cherries. Treeline treatments did change the emissions intensity with the addition of compost almost doubling emission intensity.

Potential soil management strategies for greenhouse gas mitigation within the deciduous fruit tree crop industries need to reconcile both nitrous oxide emissions and carbon sequestration and the differing timeframes and permanence of the measures. Combining these with fruit yields to give emissions intensities of production will help drive the multiple goals of greenhouse gas mitigation, food security and profitability.

2 Keywords

apples, cherries, compost, mulch, nitrous oxide, soil carbon, global warming, greenhouse gas, nitrogen.

3 Introduction

The Australian apple and pear industry, with an estimated gross value of production of $681M, is the highest value fruit industry in Australia (APAL). Production in 2015 was 295 000 tonnes of apples and 105 000 tonnes of pears. The cherry industry is another major producer, growing 8900 tonnes of cherries each year on 3700 ha with a value of $90million.

Perennial tree cropping systems have two dependant components; the treeline and the inter-row. The treeline area contains the plants and the majority of crop roots, and it is where cropping inputs such as fertilizers and water tend to be directed. Processes are more dynamic in the highly-managed treeline and so it receives more attention by orchardists.

Improving both the treeline and the inter-row however have significant potential benefits for apple and cherry productivity as well as potential to sequester carbon in soils and reduce nitrous oxide emissions, two important greenhouse gas emission mitigation options.

In an apple (cv. Royal Gala) orchard in Chile, perennial cover crops of lucerne and clover were established in the inter-row and were mown 4 times per year. After 5 years, apple yields were between 42% and 50% higher under lucerne and clover cover crops. These cover crops also contributed between 5.7 and 6.7 tonnes/ha of organic matter (dry weight) to the soil, resulting in an increase in soil organic matter of between 20.3 and 22.0 t C/ha in the top 15cm of soil over the 5 years of the experiment, compared to the cultivated control (Sanchez, Cichon et al. 2006).

A long-term study of kiwifruit and apricot orchards in Europe found that a combination of cover crops, no-tillage, compost application and mulching of pruning residues for 4 years could result in increased soil N, P and K reserves and additions of up to 16 t organic matter (dry weight) per ha per year to the soil (Montanaro, Celano et al. 2010; Xiloyannis, Dichio et al. 2010). On an average soil, this would increase soil organic matter by 1% OM per year.

Through appropriate orchard management, a large amount of SOC can be sequestered in soils. For example, (Nieto, Castro et al. 2010) estimated a potential carbon sequestration of between 0.5 and 0.6 t C/ha/yr in olive groves in a Mediterranean climate using mulches and returning prunings and other organic wastes to the soil.

Organic fertilizer can supply large amounts of carbon to the soil. In an 18-year study of pear orchards in northern Italy, comparing bare soil and inorganic fertilizer application to grassed inter-rows and organic fertilization, the soil organic carbon (SOC) was increased by 16 t C/ha/yr in the top 15cm of soil over that time (Ciavatta, Gioacchini et al. 2008). (Rahman, Holmes et al. 2010) found that organic management of kiwifruit orchards in New Zealand could produce similar increases in organic carbon in the top 15cm of soils. The use of organic sources of nutrients in the form of composts and manures can contribute to soil organic matter and has significant beneficial effects on soil biology. Recent work shows that the so-called Plant Growth Promoting Rhizobacteria (PGPRs), which include many commonly-occurring soil bacteria such as *Pseudomonas* sp., have quantifiable growth-promoting effects on plants, and can have disease suppressive effects (Choudhary, Sharma et al. 2011).

While there are a number of studies on the impact of orchard floor management on soil carbon sequestration there are only a few studies on nitrous oxide emissions with none undertaken under Australian conditions and orchard management.

This project undertook the first integrated assessment of orchard floor management on greenhouse gas mitigation, soils and productivity. Measurements of nitrous oxide was undertaken at two commercial orchards (apple and cherry) with very low baseline emissions observed. The impact of managing the treeline and inter-row with different inputs of organic matter (Lucerne and wheat straw mulch, compost) was assessed over 3 years.

This report summarises the effect of these treatments on orchard productivity, greenhouse gas mitigation and soil health. Potential soil management strategies for greenhouse gas mitigation within the deciduous fruit tree crop industries need to reconcile both nitrous oxide emissions and carbon sequestration and the differing timeframes and permanence of the measures. Combining these with fruit yields to give emissions intensities of production will help drive the multiple goals of greenhouse gas mitigation, food security and profitability.

4 Methodology

4.1 Overview of Apple Orchard, Orange NSW

4.1.1 Climate

The Orange site has a continental climate, which has a notable difference in mean maximum temperature between summer and winter (25.7 °C and 10.6 °C respectively). Rainfall in the region is generally uniform across the year, averaging 859 mm.

4.1.2 Orchard floor management practices

Four differing orchard floor management practices were monitored for greenhouse gas emissions and responding effect on fruit yield. The practices represent a range of organic matter input, ranging from none (scraped) through to mulches of differing C:N ratios (wheat straw and lucerne straw). Treatments were applied in November through to December 2013 with both lucerne straw 15 $t.ha^{-1}$ and wheat straw 13 $t.ha^{-1}$ treatments applied under the apple trees, whereas the scraped treatment continued into the interrow area. Treatments were reapplied in June 2015 at a dry weight rate of 15 $t.ha^{-1}$ lucerne straw and 13 $t.ha^{-1}$ wheat straw. Scraped plots were maintained as bare soil and sprayed with glyphosate.

4.2 Overview of Cherry Orchard, Young, NSW

4.2.1 Climate

The climate at the Young site is classified as cool temperate with uniform precipitation across the year, averaging 591 mm. The annual maximum mean temperature (1991–2015) is 30.1°C in summer and 13.2°C in winter.

4.2.2 Orchard floor management practices

Four differing orchard floor management practices were monitored for greenhouse gas emissions and responding effect on fruit yield. The practices represent a range of organic matter input, ranging from none (scraped) through to amendments of differing C:N ratios (wheat straw and compost). Treatments were applied in November through to December 2013 with both humus compost 20 $t.ha^{-1}$ and wheat straw 20 $t.ha^{-1}$ treatments applied under the apple trees, whereas the scraped treatment continues into the interrow area. Treatments were reapplied in July 2015 at a dry weight rate of 29 $t.ha^{-1}$ humus compost and 21 $t.ha^{-1}$ wheat straw. Scraped plots were cleared to bare soil and sprayed with glyphosate.

4.3 Fruit yield

4.3.1 Apples

Yield measurements were taken on site with coordination with the orchard manager. Pickers employed by the orchard were assigned specific plots to pick fruit into corresponding half-tonne bins. Plots were marked out in a colour-coded layout with matching coloured bins to ensure simple procedure for staff unfamiliar with the project. Apples remained in their original bins and were weighed at the packing shed via pallet scales (Millennium Mechatronics MI101, New Zealand).

4.3.2 Cherries

Yield measurements were taken on site with coordination with the orchard manager. Pickers employed by the orchard were assigned specific plots to pick fruit into corresponding 13kg lugs. Plots were marked out in a colour-coded layout with matching coloured lugs to ensure simple procedure for staff unfamiliar with the project. Cherries were weighed at the packing shed in lugs, transferred to quarter-tonne bins.

4.4 Soil measurements

4.4.1 Nitrous oxide emissions

Greenhouse gas samples were collected in PVC gas sampling chambers with an approximate air volume of 6.3 L that were inserted into both the inter-row and tree-row areas of the orchids. Initial samples were taken immediately after the chambers were closed lids and rubber seals. The lids have two septa, one allowing a syringe to sample the gas and the other allowing a thermometer to measure the air temperature within the chambers. A syringe was used to take 25ml gas samples which were transferred into evacuated 12ml Exetainers® (Labco Ltd, United Kingdom). The air temperature within the chambers was also recorded when the sample is taken as this influences the concentration of gases. Samples were stored at ambient temperature until analysis.

Nitrous oxide (N_2O) concentration was determined with a 8A-Shimadzu (Kyoto, Japan) Gas chromatography (GC) instrument using an Electron-capture detector (ECD). A Porapak Q (80/100, 6 ft x 1/8 in. X 2.1 mm, Sigma-Aldrich) column was used to separate the gases. Column temperature 30°C and injection temperature 70°C. Helium was the carrier gas at a pressure of 2kg/cm2. 0.5ml gas samples were injected into the ECD with a run-time of 10 min. N_2O in air at various concentrations will be used to calibrate the ECD and determine the standard curve at the beginning of each run. Reference gas samples (BOC) were used for calibration.

4.4.2 Emissions intensity

The emissions intensity of each treatment was calculated as the ratio of N_2O emissions in relation to crop yield and relates to how much N_2O was emitted per tonne of fruit harvested. Direct N_2O emissions were converted to carbon dioxide equivalents (CO_{2eq}) within a 100-year horizon by multiplying by a radiative forcing potential equivalent to CO_2 of 298 for (IPCC 2001). Yield-scaled emissions for this perennial system (CO_{2eq} Mg^{-1}) were calculated by dividing annual N_2O emissions (CO_{2eq} ha^{-1} $year^{-1}$) for the annual production cycle by total apple or cherry yield (Mg ha^{-1}).

4.4.3 Soil Carbon stocks

Soil samples were collected and analysed for bulk density, total carbon and nitrogen and total nutrients.

Soil was collected at depths of 0-15cm and 15-30cm. Two samples were taken from each depth, a bulk density core that was stored at ambient temperature and a nutrient sample that was stored on ice until transferred to a refrigerator at 4°C.

Bulk density samples were individually weighed and a small subsample of approximately 100 g was removed, weighed and dried at 105°C for 48 hours before a final weight was recorded to determine the moisture content of the soil.

Soil carbon was determined with a CNS analyser (Elementar Vario MAX CNS, Germany) following the National Soil Carbon Research Programme: Field and Laboratory Methodologies (SCaRP) (Sanderman et al.). Soil samples were dried at 40°C before sieving to 2mm to remove gravel and organic material, then ground for 2 minutes and sieved again to 53µm in preparation for analysis.

Soil nutrient analysis (pH (H_20), pH ($CaCl_2$), EC, S, P, Na, K, Ca, Mg, Al, Cl, Cu, Zn, Mn, Fe, B, NO_3-N and Organic Matter were determined using standard methodologies

4.4.4 Soil Microbial Biomass

Microbial biomass content was determined by the fumigation-extraction technique (Horwath & Paul, 1994; Michelsen et al., 2004; Ohlinger, 1995). Fresh samples were removed from refrigeration and sieved to 2mm to remove gravel and organic matter. 4 grams of soil were weighed into beakers in triplicate for control and 4 grams in triplicate for samples to be fumigated with is a glass desiccator with chloroform for 48 hours. All six sets of samples were extracted with 40ml of 0.05M potassium sulphate and filtered through Whatman no. 42 filter paper and extracts frozen until total organic carbon analysis with a Shimadzu TOC-V (Shimadzu Corp., Japan).

4.5 Articles and Factsheets

Factsheets are a very efficient method to inform the wider horticultural industry of innovative sustainable practices. A range of professional and succinct soil management factsheets were developed.

5 Outputs

5.1 Reports

5.1.1 Benchmarking nitrous oxide emissions in deciduous tree cropping systems (Appendix 1)

Swarts Nigel, Montagu Kelvin, Oliver Garth, SouthamRogers Liam, Hardie Marcus, Corkrey Ross, Rogers Gordon, Close Dugald (2016). Benchmarking nitrous oxide emissions in deciduous tree cropping systems. *Soil Research* 54, 500–511.

Abstract. Nitrous oxide (N_2O) emissions contribute 6% of the global warming effect and are derived from the activity of soil-based microorganisms involved in nitrification and denitrification processes. There is a paucity of greenhouse gas emissions data for Australia's horticulture industry.

In this study we investigated N_2O flux from two deciduous fruit tree crops, apples and cherries, in two predominant growing regions in eastern Australia, the Huon Valley in southern Tasmania (Lucaston – apples and Lower Longley – cherries), and high altitude northern New South Wales (Orange – apples and Young – cherries). Estimated from manual chamber measurements over a 12-month period, average daily emissions were very low ranging from 0.78 g N_2O-N ha^{-1} day^{-1} in the apple orchard at Lucaston to 1.86 g N_2O-N ha^{-1} day^{-1} in the cherry orchard in Lower Longley. Daily emissions were up to 50% higher in summer (maximum 5.27 g N_2O -N ha^{-1} day^{-1} at Lower Longley) than winter (maximum 2.47 g N_2O -N ha^{-1} day^{-1} at Young) across the four trial orchards. N_2O emissions were ~40% greater in the inter-row than the tree line for each orchard. Daily flux rates were used as a loss estimate for annual emissions, which ranged from 298 g N_2O -N ha^{1} $year^{-1}$ at Lucaston to 736 g N_2O -N ha^{-1} $year^{-1}$ at Lower Longley (**Figure 1**).

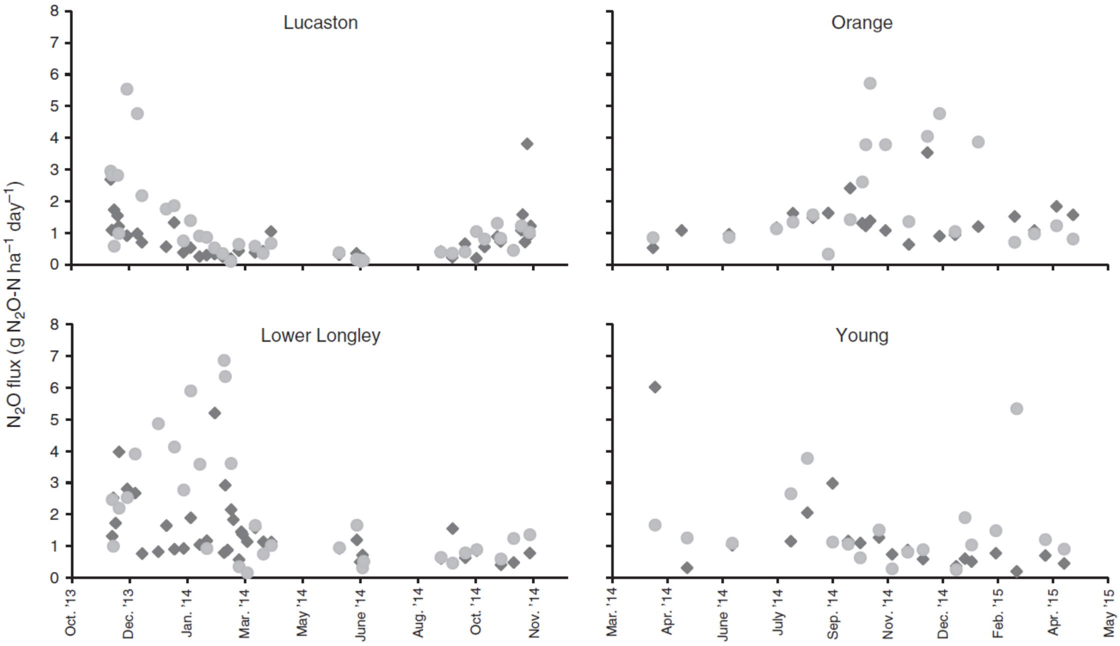

Figure 1. Average daily N_2O (g N_2O-N ha^{-1} day) emissions from apple and cherry orchards in Tasmania and New South Wales.

Emissions were poorly correlated with soil temperature, volumetric water content, water filled porosity, gravimetric water content and matric potential – with inconsistent patterns between sites, within the tree line and inter-row and between seasons. Stepwise linear regression models for the Lucaston site accounted for less than 10% of the variance in N_2O emissions, for which soil temperature was the strongest predictor.

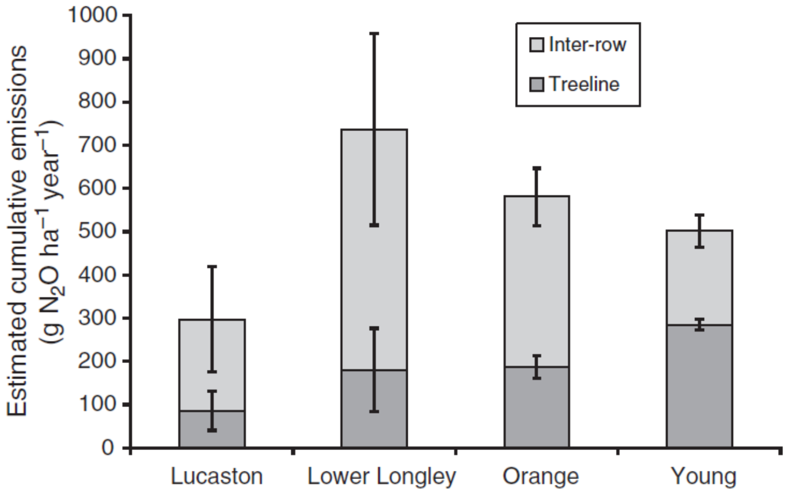

Figure 2. Cumulative N_2O (g N_2O-N ha^{-1} day^{-1} $year^{-1}$) emissions from apple and cherry orchards in Tasmania and New South Wales.

Annual N_2O emissions in deciduous tree crops were among the lowest recorded for Australian agriculture, most likely due to low rates of N fertiliser, cool temperate growing conditions and highly efficient drip irrigation systems (**Figure 2**). We recommend that optimising nutrient use efficiency with improved drainage and a reduction in soil compaction in the inter-row will facilitate further mitigation of N_2O emissions.

5.1.2 Impacts of orchard floor management on soil nitrous oxide emissions, carbon storage and productivity in an apple and cherry orchard (Appendix 2)

Montagu Kelvin, Swarts Nigel, Southam-Rogers Liam and Rogers Gordon *In Review*. Impacts of orchard floor management on soil nitrous oxide emissions, carbon storage and productivity in an apple and cherry orchard.

Abstract. Orchard floor management practices were assessed for their impacts on greenhouse gas mitigation and orchard productivity. On an apple and cherry commercial orchard four treeline treatments, 1) control - herbicides used to prevent weed growth and tree organic matter input left; 2) scrape - herbicides were used to prevent weed growth and all organic matter periodically removed 3) wheat straw mulch; 4) either compost (cherry orchard) or lucerne straw mulch (apple orchard), and two inter-row treatments, 1) control - grass sward maintained and mowed periodically with clippings left in-situ; 2) scrape, were applied.

When low C:N amendments were applied, as either lucerne straw mulch or compost, annual nitrous oxide emissions increased by 2.7 and 3.8 times, whereas wheat straw mulch or scrape treatments produced emission similar to the control (Table 1).

Table 1. Cumulative yearly nitrous oxide emissions from the treeline of two commercial orchards following the application of differing management practices. Value are the means ± standard errors.

	Apple orchard	Cherry orchard
Treeline management	*kg N_2O-N ha^{-1} $year^{-1}$*	
Control	0.478 ±0.021	0.413 ±0.045
Scrape	0.322 ±0.058	0.347 ±0.097
Wheat straw mulch	0.500 ±0.210	0.492 ±0.030
Lucerne straw mulch	1.822 ±0.456	n.a.
Compost	n.a.	1.100 ±0.079

This was due to elevated daily nitrous oxide emissions immediately following the application of lucerne straw mulch and compost and in the summer after application (Figure 3).

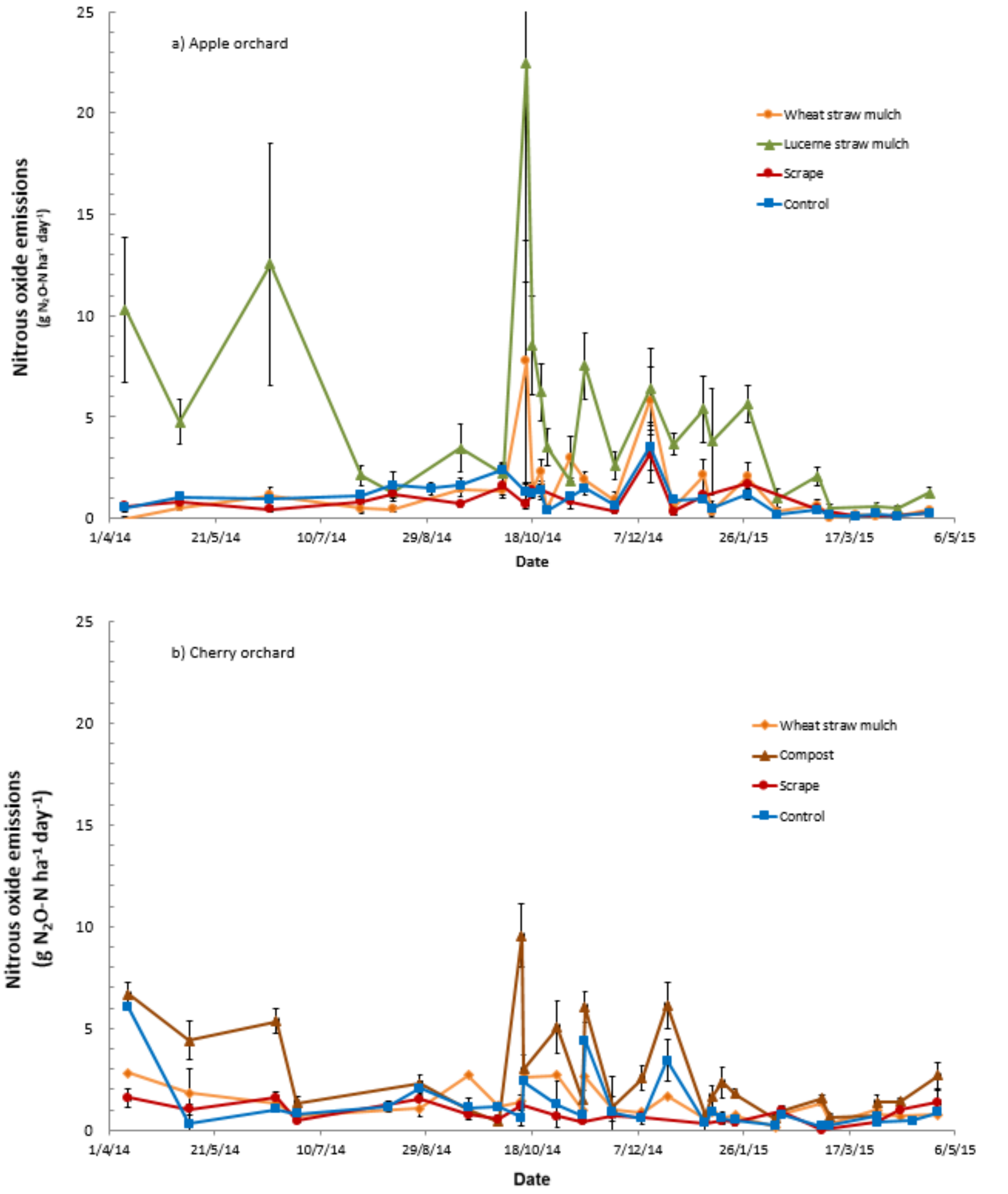

Figure 3. Daily nitrous oxide emissions from the treeline of either a) an apple or b) a cherry orchard.

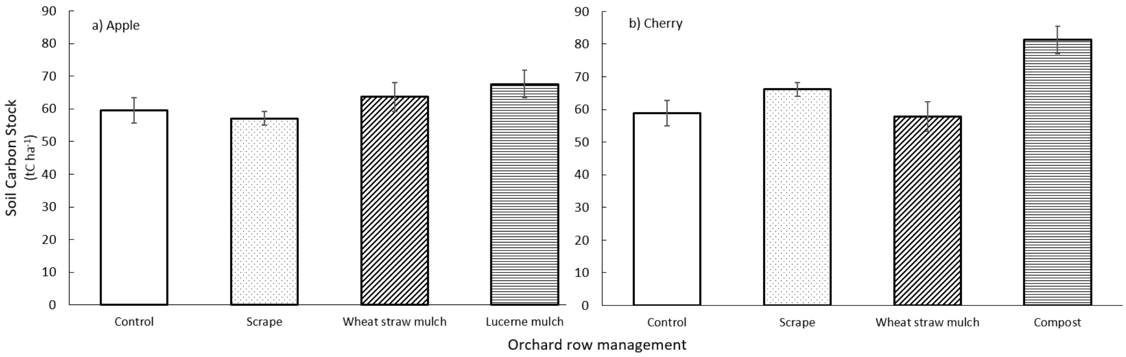

Figure 4. Soil carbon stocks to 30 cm 30 months after differing orchard management practices were applied to the tree rows at two NSW perennial orchards; a) apple orchards at Orange, b) cherry orchard at Young. Values are means ± standard errors.

An increase in soil carbon storage was only observed under the compost treatment at the cherry orchard. Cherry or apple yields were not affected by the treatments except when lucerne straw mulch was applied to the apple orchard (Figure 4).

The N_2O derived emissions intensity was lower in the apples than cherries, with the addition of compost almost doubling of emission intensity. Potential soil management strategies for greenhouse gas mitigation within the deciduous fruit tree crop industries need to reconcile both N_2O emissions and carbon sequestration and the differing timeframes and permanence of the measures. Combining these with fruit yields to give emissions intensities of production will help drive the dual goal of greenhouse gas mitigation and food production.

Table 2. Emissions intensity of apples and cherries produced under different orchard floor management practices.

	Apple orchard	Cherry orchard
Treeline management	*kg CO_2 eq Mg^{-1}*	
Control	6.93 ±1.3	13.6 ±2.5
Scrape	4.85 ±1.6	11.9 ±1.2
Wheat straw mulch	5.65 ±1.3	11.3 ±2.8
Lucerne straw mulch	7.57 ±1.8	n.a.
Compost	n.a.	24.8 ±3.8

5.1.3 Technical Report for Progress Reports - Reducing nitrous oxide emissions in key perennial horticulture industries

The technical reports describe work completed towards milestones for the DAFF FTRG R2 "Reducing nitrous oxide emissions in key perennial horticulture tree crops" project. This collaborative project between Applied Horticulture Research and Tasmanian Institute of Agriculture aims to research benchmarking and mitigation of greenhouse gas (GHG) emissions - nitrous oxide (N_2O), carbon dioxide (CO_2), and methane (CH_4) - in two key Australian horticulture industries – apples and cherries.

There were five technical reports produced over the term of the project. Technical reports 3, 4 and 5 are included as Appendix 3, Appendix 4, Appendix 5 as they contain information shared between the two projects. The technical reports;

- List the soil amendments used at all trial sites and describe how the separate plots were created in detail.
- Outline the nitrous oxide emissions measurement techniques
- Report the baseline nitrous oxide emissions
- Report fruit yield and quality data
- Report soil carbon stocks and chemical analysis results

5.1.4 Soil Health Benefits

The soil health benefits of the orchard floor treatments were assessed using soil carbon and microbial biomass and soil bulk density. Across the two orchards only the compost addition had a significant effect on these parameters (Figure 5). Neither the application of mulch nor the removal of all organic matter in the scaped treatment produced a measurable impact on soil health.

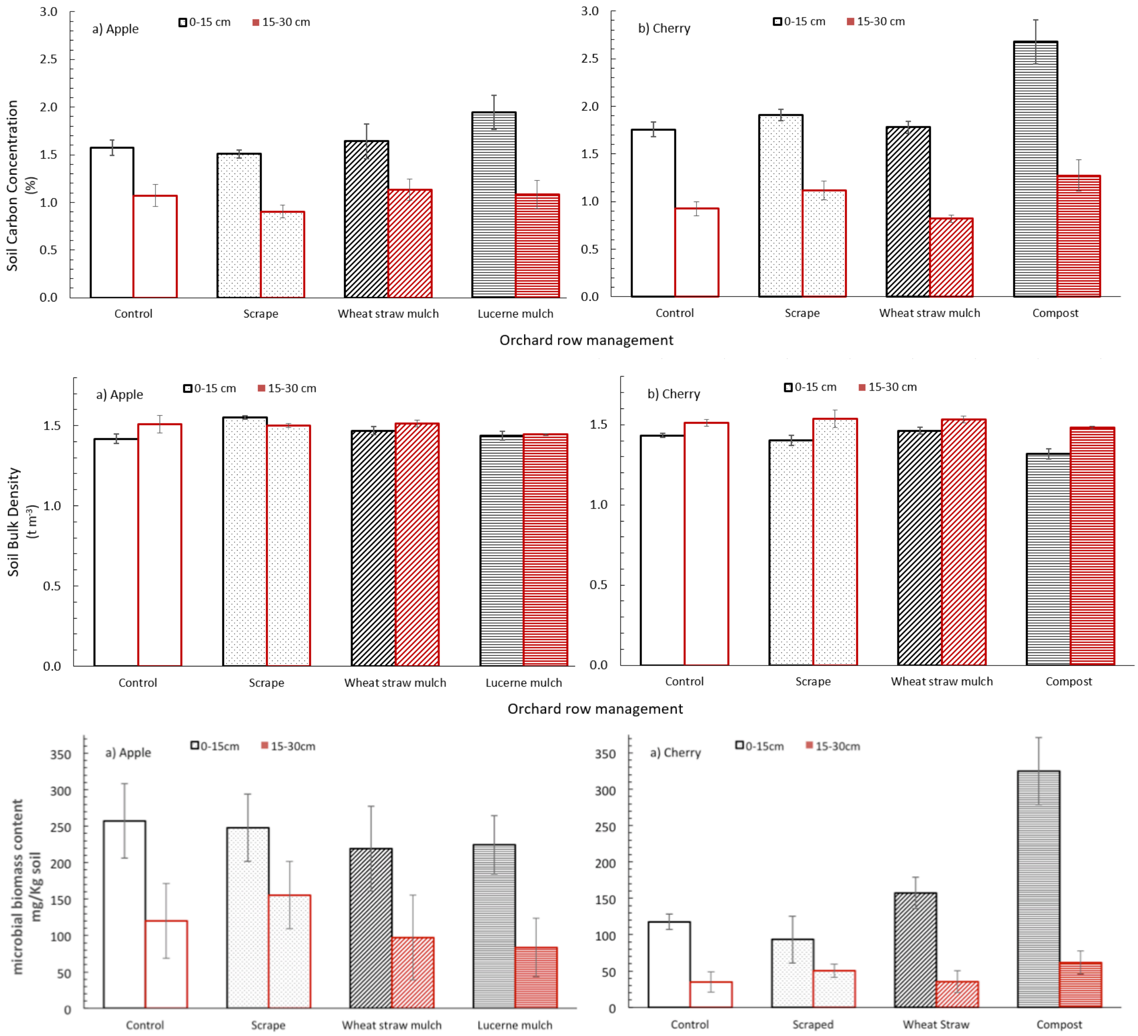

Figure 5. Soil carbon, bulk density and microbial biomass 30 months after differing orchard management practices were applied to the tree rows at two NSW perennial orchards; a) apple orchard at Orange, b) cherry orchard at Young.

5.2 Articles and Factsheets

5.2.1 Nitrous oxide emissions – something to smile about


PRODUCTS & SERVICES NEWS

Nitrous oxide emissions – something to smile about

Figure 1: Annual nitrous oxide emissions from the soil of apple and cherry orchards in Tasmania and NSW.

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An article *Nitrous oxide emissions – something to smile about* was written for the February edition of the Australian Tree Cropping Magazine and is included as **Appendix 6**. The article outlines the purpose of the study and the low emissions found in the research.

5.2.2 Is too much nitrogen a cause of poor fruit quality

The projects research partner, Tasmanian Institute of Agriculture, produced an article for the Winter edition of the Cherry Growers Australia Magazine and is included as **Appendix 7**. The article outlines the effect of applying too much nitrogen to cherry orchards.

5.2.3 TV interview

A television interview with Cathal Daynes from Applied Horticultural Research was recorded on Thursday 6th March 2014 and aired on Friday 7th March for WinTV. The interview was recorded at Peter Darley's (Day Dawn) Apple Orchard where the apple trials are being conducted.

5.2.4 Apple and cherry orchards low nitrous oxide emissions – plenty to smile


Apple and cherry orchards low nitrous oxide emissions – plenty to smile about

Nitrous oxide is a serious pollutant

Take home messages

Measurements in apple and cherry orchards in NSW and Tasmania have shown very low annual soil nitrous oxide emissions ranging between 0.3 to 0.7 kg $N2O$-N ha^{-1} $year^{-1}$. These low emissions were due to low nitrogen fertiliser use, cool temperate growing conditions and micro-irrigation systems in the orchards. The emissions intensities were very low in both apples and cherries, due to good yields and the low nitrous oxide emissions. This factsheet is included as Appendix 8**.**

6 Outcomes

Were all intended outcomes achieved?

Increased profitability through better management of the crop-row and inter-row areas, resulting in improvements in fruit quality, soil health and soil organic matter levels.

The strength of this project was the integrated assessment of orchard yields, greenhouse gases and soil under a range of orchard floor management practices in the apple and cherry orchards. The study highlighted the complexity of managing orchard floor to meet the three objects.

We identified that the orchards had very low baseline levels of soil nitrous oxide emissions. Treeline additions of mulches or compost were found to increase these emissions while, with the exception of the compost, did not result in increased soil carbon storage. However, as there are no markets for greenhouse mitigation from orchards there is no economic return to the grower.

The fruit yield or quality did not respond strongly to the different orchard floor management practice over the 2 years of the study. While some treatments increased yield (eg lucerne mulch applied to apples) there were variable effects on fruit quality. As such the orchard floor management practices would not have increased profitability over the short timeframe of this study. Given the long-term perennial nature of apple and cherry orchards, the yield and soil benefits from the compost and mulch application may only be observed in the long term.

The research found that the good yields and low nitrous oxide emissions from the orchards measured result in apples and cherries having world leading emissions intensity. This information adds to the environmental credentials of Australian grown apples and cherries.

Reliable data on the impacts of cover crops, sod culture, organic supplements and mulches on yield, fruit quality, soil moisture and soil organic matter.

The project produced the first Australian data on nitrous oxide emissions from cherry and apple orchards. This data contributed to two scientific publications in addition to articles and factsheets. This data has demonstrated that the apple and cherry orchards produced very low annual soil nitrous oxide emissions ranging between 0.3 to 0.7 kg N2O-N ha-1 year-1. The low emissions were due to low nitrogen fertiliser use, cool temperate growing conditions and micro-irrigation systems in the orchards. Higher nitrous oxide emissions from the grassed alleys were a surprise and indicated that emissions could be even lower.

The emissions intensities, that is, emissions per tonne of fruit, were very low in both apples and cherries, due to good yields and the low nitrous oxide emissions.

Potential for apple, pear and cherry growers to benefit under the carbon farming initiative using data produced by the DAFF-run part of the project.

Over the life of the project there have been substantial policy changes to the Carbon Farming Initiative and in 2015 was replaced by the Emissions Reduction Fund. To participate in the Emissions Reduction Fund an approved emissions reduction methods is required which set out the rules for estimating emissions reductions from different activities. These methods ensure that emissions reductions are genuine - that they are both real and additional to business as usual operations.

Currently, there are no approved emissions reduction methods for nitrous oxide and only limited soil carbon sequestration methods. The current soil carbon sequestration methodologies[1,2] are not applicable to the orchard floor management practices trialled at the apple and cherry orchards in New South Wales.

There is potential for the nitrous oxide data to contribute to a nitrous oxide reduction method. But given the already lower nitrous oxide emissions from both the apple and cherry orchards (Swarts et al 2016) it is unlikely that adopting practices to specifically reduce nitrous oxide emissions would produce either meaningful reductions in emissions, or any financial payments under the Emission Reduction Scheme.

Did the project achieve additional benefits?

No additional benefits were achieved beyond the primary aim of determining the productivity, soils and greenhouse gas emissions in apple and cherry orchards arising from different orchard floor management.

Are there any outcomes that are likely to be achieved in the longer term as a result of the project?

The project produced the first Australian orchard nitrous oxide data. There is the potential for this information to be used as part of the apple and cherry industries environmental credentials.

[1] Estimating sequestration of carbon in soil using default values
[2] Sequestering carbon in soils in grazing systems

7 Evaluation and Discussion

Discuss project evaluation and overall project performance

At its inception the project was to be evaluated based on rigorous on-farm trials and measurement of the impacts of inter-row management on soil carbon, greenhouse gas emissions and impacts on productivity. The publications arising from the project meet this requirement with the project making an important contribution to the understanding of how orchard floor management can impact on the productivity and greenhouse gas balance of apple and cherry orchards.

The effectiveness of project activities in delivering project outputs and achieving the intended outcomes.

The project successfully completed 3 years of field trials and monitoring at the two orchards. The data generated from the two research sites has been used to deliver the project outputs. Changes in climate change policy at the federal level, through the repel of the Clean Energy Act and associated programs (eg Carbon Farming Initiative), meant that outcome three could no longer be achieved.

Feedback on activities and the quality and usefulness of project outputs. Detail how and when feedback was sought and how this feedback was incorporated into the project.

Scientific quality and usefulness

The main form of feedback by this research project was via peer review associated with the publication of the results. As part of the publication process reviewers comments were obtained and incorporated into the revised manuscripts prior to publishing. The ongoing feedback on the scientific quality and usefulness will be obtained via the number of citations.

Industry quality and usefulness

No formal feedback was sought from the apple and cherry industries. Information was presented at the 2015 annual apple conference. The project partner also presented the results to growers in a series of workshops on nutrition and soil management. Participating growers were kept informed of the results during the trial.

The learning from the project and overall relevance to industry.

The key learnings from the project are:

- Nitrous oxide emissions in deciduous tree crops were among the lowest recorded for Australian agriculture, most likely due to low rates of N fertiliser, cool temperate growing conditions and highly efficient drip irrigation systems.
- When compared against international studies the emissions intensity were world leading, producing very low emissions during growth per tonne of fruit in both apple and cherry orchards.
- That the trade-offs between nitrous oxide emissions and soil carbon sequestration can be difficult to reconcile when developing management practices to improve soil productivity and greenhouse impacts. In this study the applications of some organic amendments increased nitrous oxide emissions but only the compost treatment increased soil carbon stocks. To fully assess the impact of the orchard floor treatments further monitoring would be required to both determine the permanence of any soil carbon sequestration, and if nitrous oxide emissions remain elevated beyond the two years measured in this study. For example, the compost treatment resulted in a 33 t CO_{2eq} ha^{-1} being sequestered in the soil, which must now remain in the soil for 100 years to reduce atmospheric forcing, while emitting an additional 0.15 t CO_{2eq} ha^{-1} $year^{-1}$ as nitrous oxide following compost addition. In the short term the compost treatment would appear to have a positive greenhouse gas balance assuming that the 33 t CO_{2eq} ha^{-1} remains in the soil and that nitrous oxide emissions following compost addition decreases over time. By comparison the lucerne straw mulch treatment has a negative greenhouse gas balance with the increased nitrous oxide emissions not off-set by any soil carbon stock increase.

8 Recommendations

The research has contributed new information on the interrelationship between apple and cherry orchard productivity, greenhouse gas balance and soil health.

Practices that increase organic matter input into soils increase the risk of nitrous oxide emissions. This is due to key role soil microbes play in nitrous oxide emissions. Balancing the benefits of adding organic matter to soil productivity with the increased risk of nitrous oxide emission is complicated.

Reducing nitrous oxide emissions also reduces the amount of nitrogen fertiliser lost and therefore improves farm profitability. Managing irrigation and nitrogen fertiliser applications to match plant requirements appears to be the most effective way of reducing nitrous oxide emissions while still producing high yields.

Achieving both soil carbon sequestration and reductions in nitrous oxide emissions is challenging. A practical framework to integrate the greenhouse gas implications of practice change for both soil carbon sequestration and reduced nitrous oxide emissions is required. This has implications for any schemes seeking to reduce emissions from the agriculture. For example, the greenhouse benefits of increasing soil carbon may be reduced by the ongoing increased risks of elevated nitrous oxide emissions.

Fruit growers should continue to focus on soil management practices which improve the health and productivity of their soils through managing soil organic matter. This may increase the risk of nitrous oxide emissions but the increased risks can be mitigated through practices such as irrigation and nitrogen management.

9 Scientific Refereed Publications

Swarts Nigel, Montagu Kelvin, Oliver Garth, SouthamRogers Liam, Hardie Marcus, Corkrey Ross, Rogers Gordon, Close Dugald (2016). Benchmarking nitrous oxide emissions in deciduous tree cropping systems. Soil Research 54, 500–511.

Montagu Kelvin, Swarts Nigel, Southam-Rogers Liam and Rogers Gordon *In Review*. Impacts of orchard floor management on soil nitrous oxide emissions, carbon storage and productivity in an apple and cherry orchard.

10 Intellectual Property/Commercialisation

None to report

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12 Acknowledgements

This project is funded through Horticulture Innovation Australia (HIA) with matched funds from the Australian Government.

Applied Horticultural Research gratefully acknowledges **Peter Darley** and **Rod Formby's** efforts in the project and for allowing trials to be established on their orchard.

Applied Horticultural Research gratefully acknowledges **Geoff Hall** and **Ahmed Abbas'** efforts in the project and for allowing trials to be established on their orchard.

13 Appendices

Appendix 1: Benchmarking nitrous oxide emissions in deciduous tree cropping systems

Appendix 2: Impacts of orchard floor management on soil nitrous oxide emissions, carbon storage and productivity in an apple and cherry orchard

Appendix 3: Technical Report 3 for the corresponding DAFF FTRG project

Appendix 4: Technical Report 4 for the corresponding DAFF FTRG project

Appendix 5: Technical Report 5 for the corresponding DAFF FTRG project

Appendix 6: Nitrous oxide emissions – something to smile about

Appendix 7: Is too much nitrogen a cause of poor fruit quality

Appendix 8: Apple and cherry orchards low nitrous oxide emissions – plenty to smile